YIELD AND YIELD COMPONENTS OF WINTER WHEAT AS INFLUENCED BY SEEDING RATE AND PLANT SPACING

by

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INTRODUCTION

Wheat is one of our most important crops, being the staple food of more than half of the world's population. In the United States, the name given to Kansas as the "Breadbasket of the World" is indicative of the importance of wheat in this region. In addition, wheat constitutes the second largest source of farm income, the first being livestock and livestock products. Because yield is directly related to income, it follows that the factors affecting yield should be thoroughly investigated. These factors include genetic, environmental, and cultural. In cultural factors seeding rate and plant spacing are important, as they determine plant population per unit area. The number and distribution of plants affects the use of water, nutrients and light.

The present study concerned seeding rate and plant spacing and their influence on grain yield, yield components (heads per unit area, seeds per head, and seed weight), and their interrelationships, and protein content. The extent of interaction between variety and these cultural treatments was of particular interest. Such information would be useful in determining whether or not cultural requirements vary for individual wheat varieties.

REVIEW OF LITERATURE

Seeding Rate

A number of workers have determined the effect of varied seeding rates with different winter wheat varieties under various conditions. Boyd (2) studied the effect of seeding rate (from one to four bushels per acre) on yield, and concluded that there was no gain by raising seeding rate beyond one and one-half bushels per acre. Hickman (11) conducted seeding experiments on wheat for a period of nine years in Ohio, using seeding rates from two to ten pecks per acre, and found that yield increased with the increasing seeding rate up to seven pecks per acre. In a similar study in Kansas, Jardine (12) found increasing yield response with the increased seeding rate up to six pecks per acre. Laude, _et_ _al_., (17), while discussing seeding rates in different locations of Kansas, pointed out that in eastern Kansas four to six pecks per acre was optimum for early seeding, but with late sowing eight pecks of seed per acre were needed. He further pointed out that fewer plants were needed in western than in eastern Kansas, to produce maximum yields.

Martin and Leighty (21) discussed the results of the experiments conducted by the Office of Central Investigations, Bureau of Plant Industry, Washington, D.C., on rate of seeding at five stations for a period varying from one to three years. They concluded that the highest yield was obtained by the seeding rates of five and six pecks per acre. Martin (19) concluded from the experiments at Belle Fourche Farms, South Dakota for

four years, that yield in wheat increased with increasing seeding rate from two to seven pecks per acre. Robertson, _et al._, (26) experimented for 18 years at Akron, Colorado, using one to five pecks seed per acre and concluded that one peck of seed was not sufficient, two-pecks rate was adequate, but three pecks or more did not increase the yield to justify the use of additional seed. He conducted these experiments on fallow land in rotation with corn.

Stephens, _et al._, (28) reported that at Moro, Oregon, the highest gross yield of Turkey wheat was obtained from five pecks seed per acre, but the maximum net yield was given by four pecks per acre. At Nephi, Utah, this variety gave an increasing yield response all through till eight pecks per acre. Stephens, _et al._, (29) found in the seeding rates and dates of planting that five pecks of seeding rate sown between September 15th and October 1st gave the maximum yield. Martin (20), while discussing the influence of rates and dates of seeding on yield at ten stations of Great Plains and four stations of Great Basin area, pointed out that maximum yield was obtained at different locations and varieties with the seeding rate ranging from four to nine pecks per acre.

Leighty and Taylor (18) conducted a seeding rate experiment in Virginia using seeding rate from two and eight pecks per acre. They found that six pecks per acre gave the highest grain yield. Yields from seeding two and three pecks per acre were significantly lower, but yields from seeding four, five, seven and eight pecks per acre were only slightly lower than six pecks per acre.

Kiesselbach, et al., (15) conducted experiments for 14 years at Nebraska using five seeding rates. He concluded that there may be a rather wide range in planting rates without materially affecting the yield. Results of experiments conducted by McKeon (22) for a period of 22 years indicated that yield increased up to 90 pounds per acre and then decreased.

Buffum (3), while studying tillering in wheat with the varying seed rates from 30 to 120 pounds per acre, found that increased seeding rate increased the number of heads per square foot, yield and seed weight. Grantham (9) in his study of the effect of rate of seeding on yield, tillering, and seed weight in ten varieties, observed that increased seeding rate decreased the yield and number of tillers per plant, but the size of the grain increased. Grantham (10) in another study with three seeding rates on 20 varieties confirmed the above findings. He also noted that tillers per plant and seed weight had important bearing on yield.

In a study of the relation of seeding practices to crop quality, Kiesselbach (14) experimented for six years at Lincoln, Nebraska, and found that increased seeding rate increased grain yield, but the number of tillers per plant was decreased. He also found that higher seeding rates produced heavier seeds and more protein in the grain. Ten Eyck and Shoesmith (31) noted an increase in yield in wheat with seeding rates up to five pecks. At six and eight pecks per acre the yield decreased. They also noted that in favorable years, yield increased with the increase in tillering. In a study of relation of some plant characteristics

to yield in winter wheat, Laude (16) found that yield increased with an increase in the number of heads per acre. He also noticed that yield was associated with test weight. In an investigation of seeding rate as a factor affecting winter wheat yield and yield components, Stickler (30) observed that seeds per head and seed weight were greater at the lowest seeding rate.

The influence of seeding rate on yield and seed weight was studied by Coffman (5) for a period of 15 years at Akron, Colorado. He found that yield increased with increased seeding rate from one to six pecks per acre. Effects upon seed weight were inconsistent. Atkinson (1) used seeding rates from 2 to 16 pecks per acre and observed that the rate of increase in yield was greatest up to six pecks seeding rate. Between six and ten pecks the increase was relatively low, and beyond ten pecks per acre there was a decreasing trend in yield. He also found that seed weight slightly increased with increased seeding rate. Das and Verma (6) used seeding rates from 40 to 140 pounds per acre and observed that a high seeding rate reduced the head-bearing tillers per plant, number of seeds per head, and seed weight. Pendleton and Dungan (24) studied the effects of seeding rate on yield and found that yield increased up to the six-pecks rate. Between six and nine pecks per acre, practically no increase occurred, and beyond nine pecks yields decreased.

According to Moss (23), the optimum seeding rate depends upon the time of seeding and moisture content in the soil. Using 25 to 70 pounds of seed per acre, he got satisfactory yield with 50 pounds. Less seed was required for early seeding than for

late seeding or for poor soil conditions.

In a study of winter wheat investigation, Kiesselbach (13) at Nebraska, found that an increase in seeding rate gave increased yield and higher protein content in the grain.

A marked difference in yield was recorded in 34 varieties tested in 144 trials by Bullen, et al., (4), who attributed these variations to genetic, geographical, seasonal, and soil factors. Georgeson (8) tested 35 varieties at varying seeding rates from 0.5 to 2.0 bushels per acre and found a marked difference in response of different varieties. Highest yield was obtained with one and one-half bushels per acre.

Plant Spacing

Tillering of wheat was studied by Buffum (3) in Wyoming, by using intra-row spacings of 1, 2, 4, and 12 inches in 36 inch rows. He found that the number of heads were three times, and yield per plant was two and one-half times in 12 inch intra-row spacing compared to one inch spacing. Percival (25) used six spacings (6x1, 6x3, 6x6, 12x6, 12x12, and 24x24 inches), and found that number of heads per plant was five times, weight of grains per head and number of grains per head was almost double in the widest spacing compared to the closest spacing. The yield in closest spacing was seven times as great as that in the widest spacing, due to higher plant population. Frankel (7) used intra-row spacing from one-half to twelve inches and found that increased spacing increased the yield per plant and number of grains per head but decreased the seed weight.

METHODS AND MATERIALS

Seeding rate and plant spacing experiments with winter wheat were conducted on the Agronomy Farm, Kansas Agricultural Experiment Station, Manhattan, Kansas, during 1961-62.

The preceding crop was oats. The soil was a Geary Silt Loam. After seedbed preparation, a fertilizer mixture consisting of ammonium nitrate (33.5% N) and treble super-phosphate (45% P_2O_5) was drilled to supply a fertility treatment of 50-50-0 pounds per acre.

The experiments were planted on September 27th and 29th, 1961, with a Planet, Jr., 300-A seeder. The row width was 12 inches. Germination trials of the seed to be sown were conducted to determine viability.

Both experiments were conducted in a split plot design, each treatment being replicated four times. The six winter wheat varieties, Bison, Cheyenne, Kaw, Ottawa, Pawnee, and Triumph, were the main plot treatments. In the seeding rate experiment, seeding rates of 6, 12, 18, 24, and 30 viable seeds per foot of row (12 in. rows) constituted the sub-plots. These rates were approximately equivalent to 30, 50, 70, 90, and 110 pounds of seed per acre, respectively. In the space-planting experiment the sub-plot treatments were plant spacings of 3, 6, 9, and 12 inches, in 12 inch rows. In order to obtain uniform distribution of plants, plots in the space-planted experiment were seeded at approximately 30 pounds per acre, and the plants were thinned out to the desired stand.

Each plot consisted of four 12-foot rows, 12 inches apart. The two center rows (ten feet in the seeding rate experiment and nine feet in the space planting experiment) were harvested for yield determination.

Weeding was done in October and February. The head-bearing tillers were counted from a three-foot section of the center rows. In the space-planted experiment, tillers on five plants were counted.

The plots were harvested by hand, labeled, dried, and then threshed and weighed. Seed weight was determined by counting and weighing 200 seeds from each plot.

After grinding, nitrogen percentage in the grain was determined by the Kjeldahl method, using boric acid in the receiving flask.

Statistical analysis was done according to procedures outlined by Snedecor (27). Sources of variation and degrees of freedom in analysis of variance are given in Table 1 and Table 2 for the seeding rate and plant spacing experiments, respectively.

Table 1. Sources of variation and degrees of freedom in analysis of variance of data from the seeding rate experiment.

Sources of variation	Degrees of freedom
Main plots	
Replications	3
Varieties (V)	5
Error (A)	15

Table 1 (concl.).

Sources of variation	Degrees of freedom
Sub-plots	
Seeding rates (R)	4
V x R	20
Error (B)	72
Total	119

Table 2. Sources of variation and degrees of freedom in analysis of variance of data from space-planted experiment.

Sources of variation	Degrees of freedom
Main plots	
Replications	3
Varieties (V)	5
Error (A)	15
Sub-plots	
Spacing (S)	3
V x S	15
Error (B)	54
Total	95

EXPERIMENTAL RESULTS

Seeding Rate Experiment

Yield Per Acre. The average yields for the different variety and seeding rate combinations are given in Table 4, (Appendix) and are presented graphically in Fig. 1. Analysis of variance indicated that differences among varieties and among seeding rates were significant at the one per cent level of probability. Kaw, Bison, Ottawa, and Pawnee yielded significantly more than Triumph and Cheyenne. Ottawa, Bison, and Triumph produced highest grain yield with seeding rate of 30 viable seeds per square foot, whereas the varieties Kaw, Pawnee, and Cheyenne gave maximum yield at seeding rate of 24 viable seeds per square foot. Ottawa showed an increased yield with an increase in seeding rate in all the five seeding rates under study. A similar trend was found with Cheyenne up to the seeding rate of 24 viable seeds per square foot.

Among the seeding rates, 30 and 24 viable seeds per square foot produced significantly more grain yield than 18-, 12-, and 6 viable seeds per square foot. All the varieties under study produced more yield at 12 viable seeds than 6 viable seeds, but at 18 viable seeds per square foot only Pawnee, Cheyenne, and Ottawa still followed the increasing trend. The rate of increase was not as high as from 6 to 12 viable seeds per square foot.

The variety X seeding rate interaction, which was significant at the ten per cent level of probability, was attributed to the inconsistent responses of Kaw, Triumph, and Bison.

Number of Heads per Square Foot. Statistical analysis of

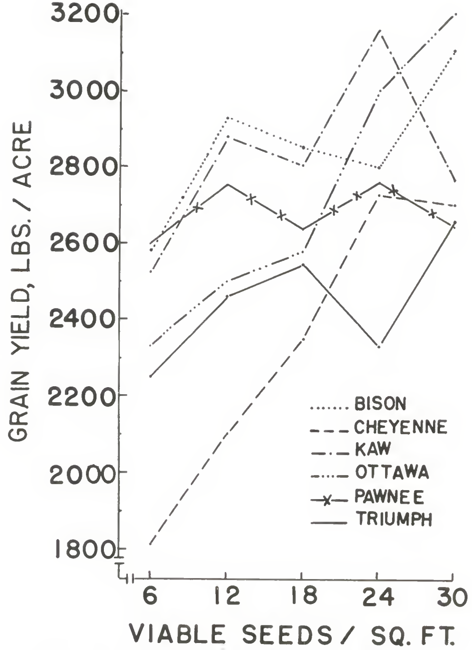

Figure 1. Grain yield as influenced by variety and seeding rate.

data on heads per square foot indicated that both the variety and seeding rate effects were significant at one per cent level of significance. As noted in Table 5, and Fig. 2, Ottawa produced a significantly greater number of heads per square foot than did the other varieties. Bison produced increased number of heads per square foot in all the rates under study. A similar trend was found in Ottawa up to 24 viable seeds per square foot. The other varieties did not show a definite trend. Bison, Pawnee, Triumph, and Cheyenne produced highest number of heads per square foot with the seeding rate of 30 viable seeds per square foot. Ottawa and Kaw produced maximum number of heads with 24 viable seeds per square foot.

Interaction was not noted between varieties and seeding rates. Tillering was insufficient to fully compensate for reduced stands.

<u>Number of Seeds Per Head</u>. The average values for the number of seeds per head are shown in Table 6 and Fig. 3. Differences due to varieties and seeding rates were significant at five and one per cent level, respectively. The interaction between varieties X seeding rate was non-significant. Cheyenne produced significantly more seeds per head than all other varieties. Bison produced a decreasing number of seeds per head all through the increasing seed rates used in this experiment. Ottawa showed decreased number of seeds per head up to 24 viable seeds per square foot. The varieties Pawnee, Bison and Ottawa produced more seeds per head with six viable seeds per square foot, whereas in Cheyenne, Triumph, and Kaw, maximum number of seeds per head

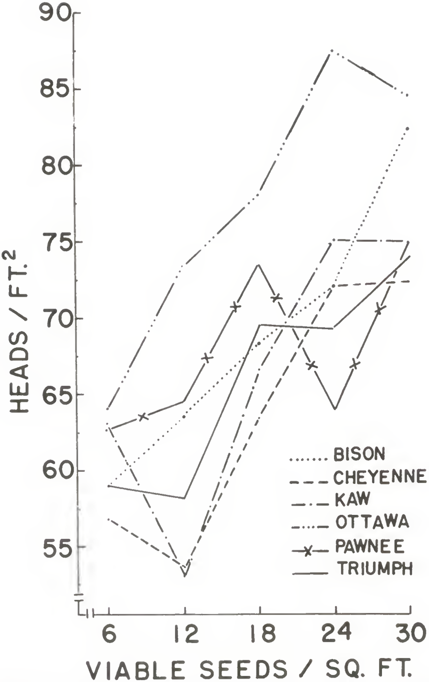

Figure 2. Number of heads per square foot as influenced by variety and seeding rate.

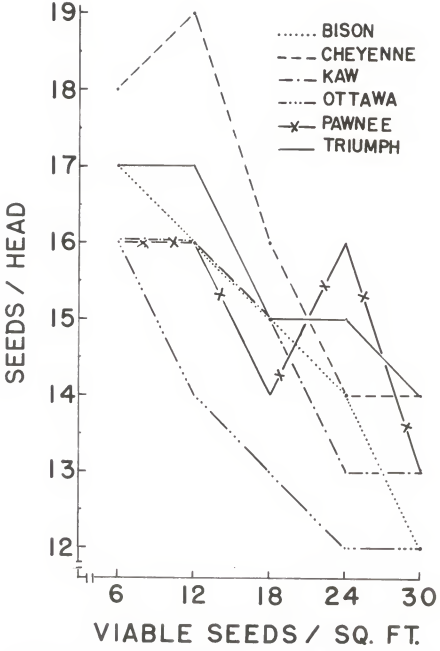

Figure 3. Influence of variety and seeding rate on number of seeds per head.

was produced by 12 viable seeds per square foot.

As shown in Table 6, the seeding rates made three groups significantly different from each other. The differences between the seeding rates of 6 and 12, 18 and 24, and 24 and 30 viable seeds per square foot were non-significant.

Seed Weight. Statistical analysis of the data shown in Table 7 and Fig. 4, revealed highly significant variety and seeding rate differences. Interaction was not detected. The seed weight of Bison was significantly heavier than that of the other varieties. Triumph ranked second and significantly heavier than Kaw, Pawnee, Cheyenne, and Ottawa. Bison, Triumph, and Pawnee produced heaviest seeds at the seeding rate of six viable seeds per square foot, Kaw and Ottawa with 12 viable seeds, and Cheyenne with 18 viable seeds per square foot.

The seeding rate means fell into two groups. The first group consisted of 6 and 12 viable seeds per square foot, which produced significantly heavier seeds than rates of 30, 24, and 18 viable seeds per square foot.

Protein Percentage in Grain. The average values of the protein percentage in the grain are shown in Table 8 and Fig. 5. Highly significant differences were found both among varieties and among seeding rates. The interaction between varieties X seeding rates was non-significant. Triumph contained the highest amount of protein of all varieties under study. A seeding rate of six viable seeds per square foot gave the highest protein percentage in Triumph, Bison, Ottawa, Cheyenne, and Kaw. Pawnee showed the highest protein percentage with the seeding rate of 12

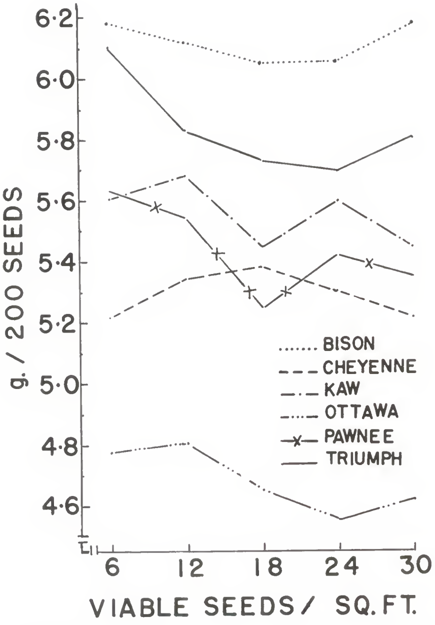

Figure 4. Seed weight as influenced by variety and seeding rate.

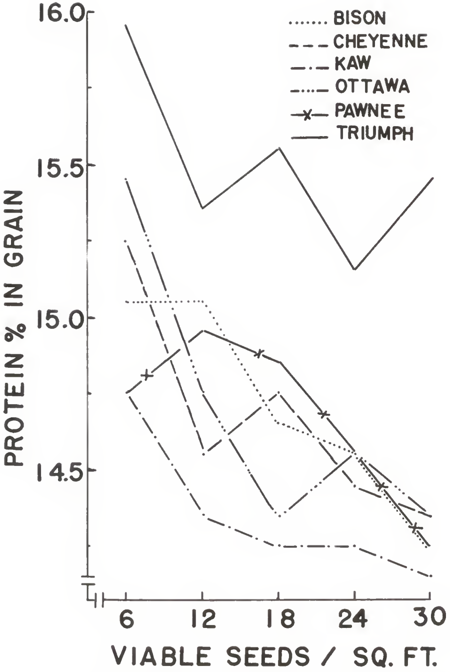

Figure 5. Protein in grain as influenced by variety and seeding rate.

viable seeds per square foot.

Plant Spacing Experiment

Yield Per Acre. Differences in grain yield (Table 9) due to variety were non-significant, but were highly significant (at one per cent level) for plant spacing. The data are shown in Fig. 6. In order of decreasing yield, varieties ranked as Bison, Ottawa, Pawnee, Triumph, Cheyenne, and Kaw. Among the spacings, three inches gave significantly more yield than all other spacings; six inches was superior to 9 or 12 inches. The rate of decrease in yield was more in spacing between 3 and 6, 6 and 9 inches, than between 9 and 12 inches for all varieties. Interaction between variety x spacing was not found.

Yield Per Plant. Yield per plant is shown in Table 10, Fig. 7. Statistical analysis revealed non-significant differences among varieties, but differences due to spacing were significant at one per cent level of significance. Interaction was not detected.

The wider spacings gave significantly higher yield per plant than others in the order of 12, 9, 6, and 3 inches. The grain yield in 6, 9, and 12 inches was approximately one and one-half, two, and two and one-half times that of the three inch spacing. However, the plant population was decreased to one-half, one-third, and one-fourth respectively, that of the three inch spacing. Thus, the reduction in plant population was greater than the increase in yield per plant. Consequently, yield per unit area was greater with a higher plant population rather than with

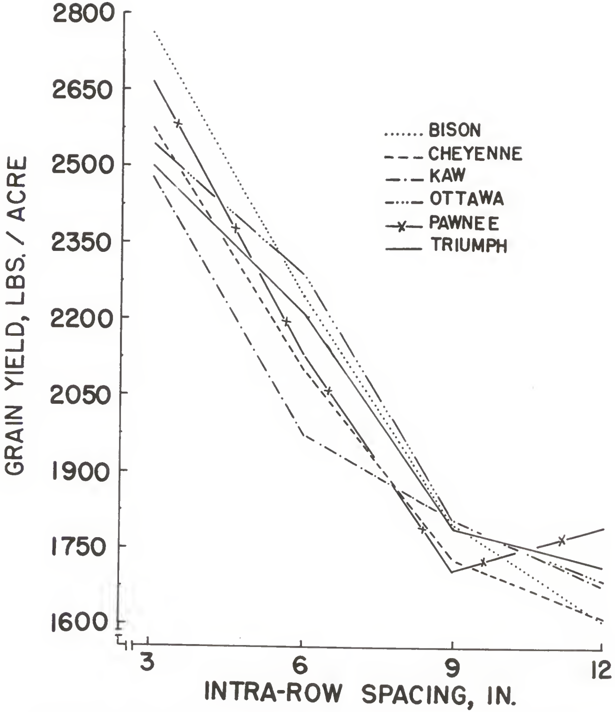

Figure 6. Grain yield as influenced by variety and Plant spacing.

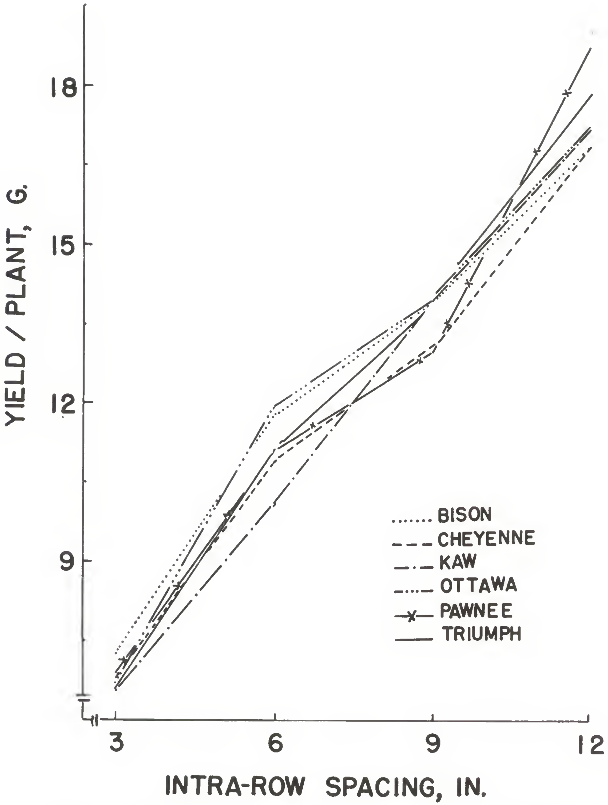

Figure 7. Grain yield per plant as influenced by variety and plant spacing.

the higher yield per plant.

Number of Heads per Square Foot. The average number of heads per square foot are shown in Table 11, and in Fig. 8. Differences among varieties were significant at the five per cent level and among spacings at the one per cent level of significance. The variety x spacing interaction was non-significant. The varieties fell into two significant groups--Pawnee, Ottawa, Cheyenne, and Kaw; and Ottawa, Cheyenne, Kaw, Triumph, and Bison. Pawnee gave significantly higher number of heads per square foot than Triumph and Bison. The maximum number of heads per square foot was obtained with the three inch spacing in all the varieties.

The closer plant spacings produced significantly higher number of heads per square foot than others in the order of 3, 6, 9, and 12 inches.

Number of Seeds per Head. Statistical analysis of data (Table 12, Fig. 9) revealed no significant differences among varieties, and highly significant (one per cent level) differences among spacings. Interaction was not found.

The varieties ranked as Ottawa, Cheyenne, Bison, Kaw, Pawnee, and Triumph. All varieties except Ottawa produced the greatest number of seeds at 12 inches.

Seed Weight. Analysis of variance of data (Table 13, Figure 10) revealed the varietal differences to be significant at one per cent level. Spacing differences were small and non-significant. All the varieties except Triumph and Bison gave statistically heavier seeds over each other in the order of Triumph, Bison, Kaw, Pawnee, Cheyenne, and Ottawa.

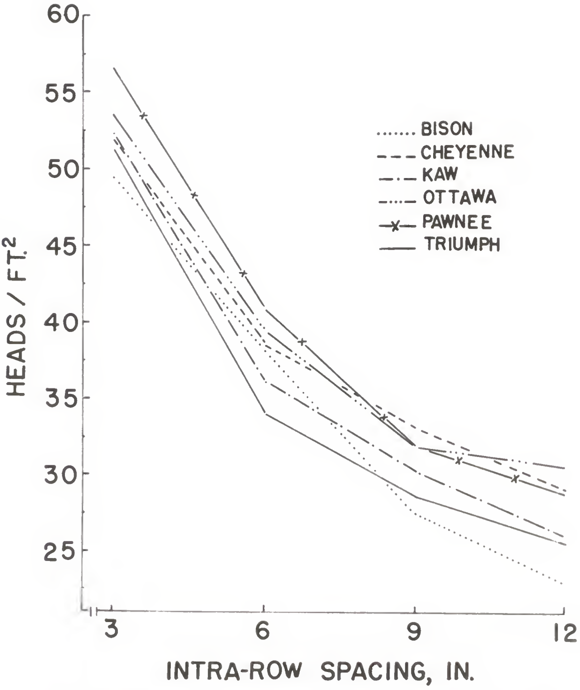

Figure 8. Number of heads per square foot as influenced by variety and plant spacing.

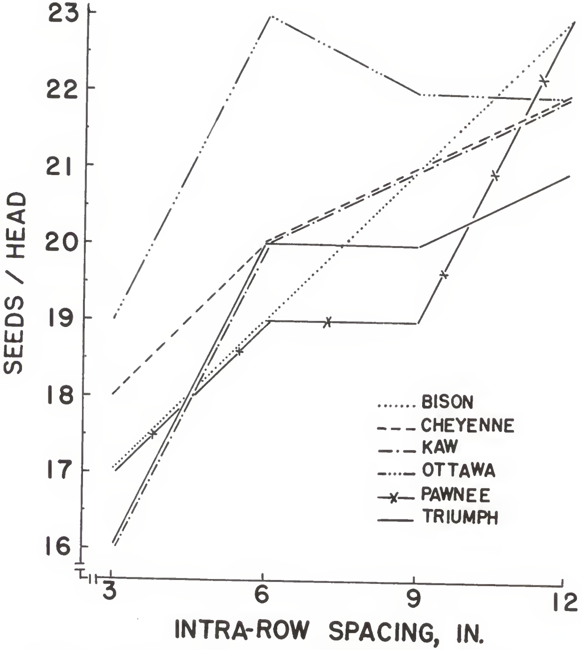

Figure 9. Influence of variety and plant spacing on number of seeds per head.

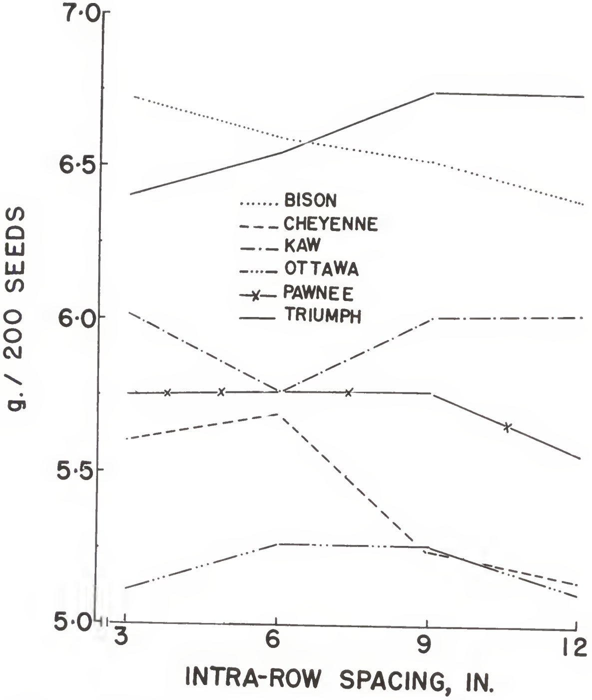

Figure 10. Seed weight as influenced by variety and plant spacing.

A significant interaction was found between variety x spacing in this experiment due to indifferent response of Triumph, Kaw, and Cheyenne at different spacings.

Protein Percentage in Grain. The varieties fell into two statistically significant groups as indicated in Table 14 and represented graphically in Fig. 11. All varieties except Cheyenne contained the highest amount of nitrogen at the 12 inch spacing and Cheyenne at nine inch spacing.

The wider plant spacings produced significantly more protein than others in the ranking order of 12, 9, 6, and 3 inches.

The interaction between varieties and spacings was significant due to indifferent response of Kaw, Bison, and Cheyenne.

DISCUSSION

Differences in the variety yields were non-significant in the spaced-planting and significant in the seeding rate experiment. This suggested that greater yield differences among varieties would be expected at a high than at a low plant density. However, in both experiments all varieties except Kaw maintained the same order of ranking.

Yield per unit area increased with increased seeding rate and closer plant spacing. With higher plant population per unit area, yield per plant was reduced due to competition. In the spacing experiment, grain yield in 6, 9, and 12 inches was one and one-half, two, and two and one-half times respectively, when compared with the three inch spacing. The corresponding plant number per unit area was one-half, one-third, and one-fourth,

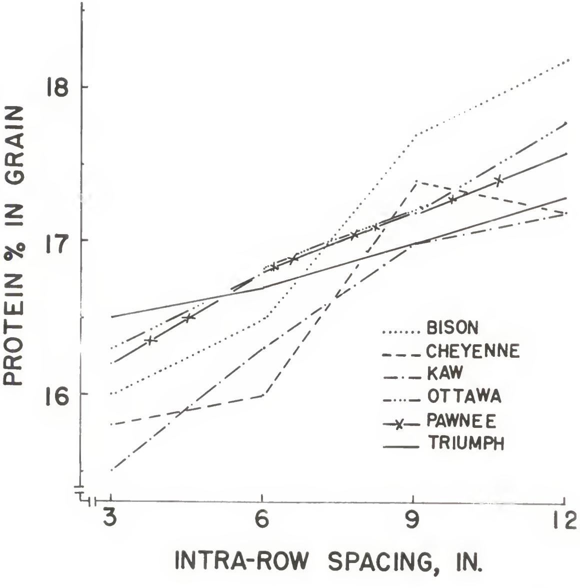

Figure 11. Protein percentage in grain as influenced by variety and plant spacing.

respectively, that of the three inch spacing. The increased yield per unit area was attributed to the increase in plant number which was relatively greater than the reduction in yield per plant. Several investigators (5, 12, 20, 21, 24, 28, 29, and 31) noted increased yield with the increasing seeding rate ranging from four to ten pecks per acre. Hickman (11) and Martin (19) obtained the maximum yield with the seeding rate of seven pecks per acre. In the present study the maximum yield was obtained with the seeding rate of 30 viable seeds per square foot, (approximately 110 pounds or seven pecks per acre). In the spacing experiment, highest yield was obtained with the intra-row spacing of three inches. The results are in accord with those of Percival (25) and Frankel (7).

The number of heads per square foot increased with increased seeding rate and decreased plant spacing. That is, the higher plant population per unit area produced more heads per square foot, in spite of the fact that the number of heads per plant was reduced. This increase in number was attributed to the plant population per unit area which was relatively greater than the reduction in number of heads. Buffum (3) and Stickler (30) found increased number of heads with increased seeding rates, and Buffum (3) and Percival (25) observed increased number of heads per unit area with closer spacings.

When the seeding rate was increased or plant spacing decreased, the number of seeds per head was also decreased. In the seeding rate experiment the variety ranking for number of seeds per head was found to be the reverse of that of the number of

heads per square foot. The higher the number of heads per unit area produced, lesser will be the number of seeds per head. Das and Verma (6) and Stickler (30) also found that the number of seeds decreased with the increasing seeding rate. Percival (25) noted that number of seeds increased with the increased spacing.

In both experiments, all the varieties except Kaw and Bison ranked in the same order for seed weight. In general, seed weight increased with closer plant spacings and higher seeding rates, because fewer seeds per head were produced with high stand density. Buffum (3) and Grantham (9) found that the seed weight increased with the increasing seed rate.

Simple and partial correlation coefficients for yield and yield components are given in Table 3. The values indicated a highly significant (one per cent level) positive correlation between yield and number of heads per square foot in both the experiments. Yield was significantly correlated with seed weight in the seeding rate experiment. Highly significant negative correlation was found between the number of heads per square foot and number of seeds per head in both experiments. The number of seeds per head was negatively correlated with seed weight in the spacing experiment. The results indicated that the number of heads per square foot was closely associated with the yield, and hence, both variables should be evaluated. Seed weight and number of seeds per head were not closely related to yield in this study.

Decreased seeding rates (increased plant spacing) produced highest protein content in the grain. This was possibly because

Table 3. Simple and partial correlation coefficients for yield and yield components and between the yield components.

Variables Correlated	"r" values	
	Seeding rate experiment	Spacing experiment
Yield vs. No. of heads per sq. ft.	.7142**	.9511**
Yield vs. No. of heads per sq. ft. with No. of seeds per head and seed weight constant	.5590**	.8594**
Yield vs. No. of seeds per head	-.7437**	-.7804**
Yield vs. No. of seeds per head with No. of heads per sq. ft. and seed weight constant	.1418	-.1699
Yield vs. seed weight	-.0087	.0009
Yield vs. seed weight with No. of heads per sq. ft. and No. of seeds per head constant	.3808*	-.2920
No. of heads per sq. ft. vs. No. of seeds per head	-.9462**	-.8082**
No. of heads per sq. ft. vs. No. of seeds per head with seed weight constant	-.9443**	-.8243**
No. of heads per sq. ft. vs. seed weight	-.4061*	-.0743
No. of heads per sq. ft. vs. seed weight with No. of seeds per head constant	-.3008	-.2737
No. of seeds per head vs. seed weight	.3093	-.2898
No. of seeds per head vs. seed weight with No. of heads per sq. ft. constant	-.2537	-.5956**

plants with wider spacing could obtain more nitrogen, and consequently, grain was richer in protein. These findings are in contrast to those of Kiesselbach (13), who found increased protein with increased seeding rates.

The variety x seeding rate interaction was significant at ten per cent level in the seeding rate experiment and at five per cent level for seed weight and protein content in the spacing experiment. This suggested only a slight tendency for differential varietal response to the treatments under study. Hence it was concluded that cultural requirements of present-day wheat varieties are similar.

This close correlation between yield and number of heads per unit area suggested that more emphasis should be given to obtain greater stand density.

SUMMARY AND CONCLUSIONS

A study involving different seeding rates and plant spacings of different winter wheat varieties was conducted on the Agronomy Farm, Kansas Agricultural Experiment Station, Manhattan, Kansas, in 1961-62.

In the first experiment, six varieties were sown at the rates of 6, 12, 18, 24, and 30 viable seeds per square foot. In the second test, the six varieties were grown at plant spacings of 3, 6, 9, and 12 inches in 12-inch rows.

Significant differences in grain yield were found among varieties in seeding rate experiment. Kaw, Bison, Ottawa, and Pawnee yielded significantly more than Triumph and Cheyenne. Variety

differences in the space-planted experiment were non-significant.

Yield per acre was greater with the closest spacing and highest seeding rate. This emphasized the importance of plant number rather than yield per plant. The greater mean yield per acre in the seeding rate experiment than in the space planted experiment was another point in support of importance of plant population per unit area for yield.

Yield per plant increased with increased spacing, because of less inter-plant competition. Yield per plant in the 6, 9, and 12 inch spacings was one and one-half, two, and two and one-half times when compared with three inch spacing. The corresponding number of plants per unit area was one-half, one-third, and one-fourth respectively. Yield per plant was higher with wider spacings, but a relatively greater reduction in plant number compared with an increase in spacing, decreased the yield per unit area.

The variety x seeding rate interaction was significant at ten per cent level indicating a tendency for differential yield response of varieties to the different seeding rates, due to difference in plant population per unit area.

Number of heads per square foot increased with an increase in seeding rate and decrease in plant spacing. In the seeding rate experiment the varieties ranked almost in the same order as for grain yield.

Number of seeds per head decreased in the higher seeding rates and closer spacings. In the seeding rate experiment, varieties ranked in reverse order to that in the number of heads per

square foot.

Seed weight increased with the closer spacing and higher seeding rate.

A highly significant (one per cent level) positive correlation was found between yield and number of heads per unit area in both experiments. Yield was significantly correlated (five per cent level) with seed weight in the seeding rate experiment. Significant negative correlation existed in the number of heads per square foot and number of seeds per head. Number of seeds per head and yield were not significantly related in either experiment.

The protein percentage of the grain increased with increased spacing and decreased seeding rate.

These results suggest very little tendency for differential varietal response (as indicated by the presence of interaction only in three cases) with the treatments under trial. Hence, in general, the varieties under trial responded similarly to the treatments under study. The findings also suggest that particular attention be paid to obtaining good uniform stands, since the number of heads per square foot was correlated with grain yield.

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APPENDIX

Table 4. Grain yield (in pounds per acre) as influenced by variety and seeding rate.

Variety	Viable seeds per sq. ft.					Varietal mean
	6	12	18	24	30	
Bison	2384	2935	2851	2799	3109	2816
Cheyenne	1807	2103	2354	2731	2706	2340
Kaw	2521	2881	2805	3161	2768	2827
Ottawa	2336	2498	2582	3003	3206	2725
Pawnee	2595	2747	2642	2762	2646	2678
Triumph	2248	2460	2546	2336	2659	2450
Seeding rate mean	2315	2604	2630	2799	2849	

LSD at 5%: Varieties = 172.1

Spacings = 172.1

Variety	Kaw	Bison	Ottawa	Pawnee	Triumph	Cheyenne
Ranking	2827	2816	2725	2678	2450	2340

Seeding rate (viable seed/ sq. ft.)	30	24	18	12	6
Ranking	2849	2799	2630	2604	2315

Means underscored with the same line do not differ significantly.

Table 5. Number of heads per square foot as influenced by variety and seeding rate.

Variety	Viable seeds per sq. ft.					Varietal mean
	6	12	18	24	30	
Bison	58.9	63.5	68.3	72.1	82.4	69.0
Cheyenne	56.7	53.6	63.4	72.1	72.4	63.6
Kaw	63.1	53.2	66.5	75.1	74.9	68.6
Ottawa	64.0	73.3	78.0	87.5	84.6	77.5
Pawnee	62.7	64.6	73.5	64.0	74.9	67.9
Triumph	58.9	58.2	69.5	69.3	74.0	66.0
Seeding rate mean	60.7	61.1	69.9	73.4	77.2	

LSD at 5%: Varieties = 2.95

Seeding rates = 4.50

Variety	Ottawa	Bison	Kaw	Pawnee	Triumph	Cheyenne
Ranking	77.5	69.0	68.6	67.9	66.0	63.6

Seeding rate (viable seed/ sq. ft.)	30	24	18	12	6
Ranking	77.2	73.4	69.9	61.1	60.7

Means underscored with the same line do not differ significantly.

Table 6. Influence of variety and seeding rate on number of seeds per head.

Variety	Viable seeds per sq. ft.					Varietal mean
	6	12	18	24	30	
Bison	17	16	15	14	12	14.8
Cheyenne	18	19	16	14	14	16.2
Kaw	16	16	15	13	13	14.6
Ottawa	16	14	13	12	12	13.4
Pawnee	16	16	14	16	13	15.0
Triumph	17	17	15	15	14	15.6
Seeding rate mean	16.7	16.3	14.7	14.0	13.0	

LSD at 5%: Varieties = 0.51

Seeding rates = 1.10

Variety	Cheyenne	Triumph	Pawnee	Bison	Kaw	Ottawa
Ranking	16.2	15.6	15.0	14.8	14.6	13.4

Seeding rate (viable seed/ sq. ft.)	6	12	18	24	30
Ranking	16.7	16.3	14.7	14.0	13.0

Means underscored with the same line do not differ significantly.

Table 7. Weight of 200 seeds (g.) as influenced by variety and seeding rate.

Variety	Viable seeds per sq. ft.					Varietal mean
	6	12	18	24	30	
Bison	6.18	6.12	6.05	6.05	6.18	6.12
Cheyenne	5.22	5.34	5.38	5.30	5.22	5.29
Kaw	5.61	5.68	5.45	5.59	5.45	5.56
Ottawa	4.77	4.81	4.65	4.55	4.62	4.68
Pawnee	5.63	5.54	5.25	5.42	5.35	5.44
Triumph	6.10	5.83	5.73	5.69	5.81	5.83
Seeding rate mean	5.59	5.55	5.42	5.43	5.44	

LSD at 5%: Varieties = 0.227

Seeding rates = 0.113

Variety	Bison	Triumph	Kaw	Pawnee	Cheyenne	Ottawa
Ranking	6.12	5.83	5.56	5.44	5.29	4.68

Seeding rate (viable seed/ sq. ft.)	6	12	30	24	18
Ranking	5.59	5.55	5.44	5.43	5.42

Means underscored with the same line do not differ significantly.

Table 8. Protein percentage in grain as influenced by variety and seeding rate.

Variety	Intra-row spacing (inches)					Variety mean
	6	12	18	24	30	
Bison	15.3	15.3	14.9	14.8	14.5	15.0
Cheyenne	15.5	14.8	15.0	14.7	14.6	14.9
Kaw	15.0	14.6	14.5	14.5	14.4	14.6
Ottawa	15.7	15.0	14.6	14.8	14.6	15.0
Pawnee	15.0	15.2	15.1	14.8	14.5	14.9
Triumph	16.2	15.6	15.8	15.4	15.7	15.7
Spacing mean	15.4	15.1	15.0	14.8	14.8	

LSD at 5%: Varieties = .468

Seeding rate = .638

Variety	Triumph	Bison	Ottawa	Pawnee	Cheyenne	Kaw
Ranking	15.7	15.0	15.0	14.9	14.9	14.6

Seeding rate	6	12	18	24	30
Ranking	15.4	15.1	15.0	14.8	14.8

Means underscored by the same line do not differ significantly.

Table 9. Grain yield (in pounds per acre) as influenced by variety and plant spacing.

Variety	Intra-row spacing (inches)				Variety mean
	3	6	9	12	
		(lbs./A.)			
Bison	2761	2258	1805	1614	2110
Cheyenne	2574	2103	1734	1615	2007
Kaw	2483	1974	1810	1679	1987
Ottawa	2545	2287	1801	1685	2080
Pawnee	2662	2146	1706	1794	2077
Triumph	2499	2157	1790	1718	2041
Spacing mean	2587	2154	1774	1684	

LSD at 5% spacing = 153.4

Variety	Bison	Ottawa	Pawnee	Triumph	Cheyenne	Kaw
Ranking	2110	2080	2077	2041	2007	1987

Spacing	3	6	9	12
Ranking	2587	2154	1774	1684

Means underscored by the same line do not differ significantly.

Table 10. Grain yield per plant (g.) as influenced by variety and plant spacing.

Variety	Intra-row spacing (inches)				Variety mean
	3	6	9	12	
Bison	7.2	11.8	14.1	16.8	12.5
Cheyenne	6.7	11.0	13.5	16.8	12.0
Kaw	6.5	10.3	14.1	17.5	12.1
Ottawa	6.6	11.9	14.1	17.5	12.5
Pawnee	6.9	11.2	13.3	18.7	12.5
Triumph	6.5	11.2	14.0	17.9	12.4
Spacing mean	6.7	11.2	13.9	17.5	

LSD at 5% spacing = 1.14

Variety	Ottawa	Pawnee	Bison	Triumph	Kaw	Cheyenne
Ranking	12.5	12.5	12.5	12.4	12.1	12.0

Spacing	12	9	6	3
Ranking	17.5	13.9	11.2	6.7

Means underscored by the same line do not differ significantly.

Table 11. Number of heads per square foot as influenced by variety and plant spacing.

Variety	Intra-row spacing (inches)				Variety mean
	3	6	9	12	
Bison	49.5	38.3	27.6	23.0	34.6
Cheyenne	52.1	38.6	33.3	29.3	38.3
Kaw	52.4	36.1	30.4	26.3	36.3
Ottawa	53.7	39.6	32.0	30.7	39.0
Pawnee	56.6	40.9	31.9	29.2	39.7
Triumph	51.3	34.1	28.6	25.7	34.9
Spacing mean	52.6	37.9	30.6	27.4	

LSD at 5%: Varieties = 4.64

Spacing = 1.96

Variety	Pawnee	Ottawa	Cheyenne	Kaw	Triumph	Bison
Ranking	39.7	39.0	38.3	36.3	34.9	34.6

Spacing	3	6	9	12
Ranking	52.6	37.9	30.6	27.4

Means underscored by the same line do not differ significantly.

Table 12. Influence of variety and plant spacing on number of seeds per head.

Variety	Intra-row spacing (inches)				Variety mean
	3	6	9	12	
Bison	17	19	21	23	20.0
Cheyenne	18	20	21	22	20.3
Kaw	16	20	21	22	19.8
Ottawa	19	23	22	22	21.5
Pawnee	17	19	19	23	19.5
Triumph	16	20	20	21	19.3
Spacing mean	17.2	20.2	20.7	22.2	

LSD at 5% spacing = 1.44

Variety	Ottawa	Cheyenne	Bison	Kaw	Pawnee	Triumph
Ranking	21.5	20.3	20.0	19.8	19.5	19.3

Spacing	12	9	6	3
Ranking	22.2	20.7	20.2	17.2

Means underscored by the same line do not differ significantly.

Table 13. Weight of 200 seeds (g.) as influenced by variety and plant spacing.

Variety	Intra-row spacing (inches) 3	6	9	12	Variety mean
Bison	6.74	6.59	6.54	6.38	6.56
Cheyenne	5.60	5.68	5.26	5.16	5.43
Kaw	6.02	5.77	6.02	6.04	5.96
Ottawa	5.11	5.28	5.28	5.13	5.20
Pawnee	5.75	5.77	5.76	5.57	5.71
Triumph	6.40	6.56	6.75	6.75	6.62
Spacing mean	5.94	5.94	5.94	5.84	

LSD at 5%: Varieties = .168

Variety and Spacing = .445

Variety	Triumph	Bison	Kaw	Pawnee	Cheyenne	Ottawa
Ranking	6.62	6.56	5.96	5.71	5.43	5.20

Spacing	6	3	9	12
Ranking	5.94	5.94	5.94	5.84

Means underscored by the same line do not differ significantly.

Table 14. Protein percentage in grain as influenced by variety and spacing.

Variety	Intra-row spacing (inches)				Variety mean
	3	6	9	12	
Bison	16.0	16.5	17.7	18.2	17.1
Cheyenne	15.8	16.0	17.4	17.2	16.6
Kaw	15.0	16.8	17.0	17.2	16.5
Ottawa	16.3	16.8	17.2	17.8	17.0
Pawnee	16.2	16.8	17.2	17.6	16.9
Triumph	16.5	16.7	17.0	17.3	16.9
Spacing mean	16.0	16.6	17.2	17.5	

LSD at 5%: Varieties = .376

Spacing = .279

Interaction = .685

Variety	Bison	Ottawa	Pawnee	Triumph	Cheyenne	Kaw
Ranking	17.1	17.0	16.9	16.9	16.6	16.5

Spacing	12	9	6	3
Ranking	17.5	17.2	16.6	16.0

Means underscored by the same line do not differ significantly.

YIELD AND YIELD COMPONENTS OF WINTER WHEAT AS INFLUENCED BY SEEDING RATE AND PLANT SPACING

by

MOHAMMED KHURSHEED AHMED

B. S., Osmania University--India, 1953

AN ABSTRACT OF A MASTER'S THESIS

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MASTER OF SCIENCE

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Two experiments, involving seeding rate and plant spacing of six winter wheat varieties, were conducted on the Agronomy Farm, Kansas Agricultural Experiment Station, Manhattan, Kansas.

Significant differences in grain yield were found among varieties in the seeding rate experiment. In ranking, Kaw, Bison, Ottawa and Pawnee yielded significantly more than Triumph and Cheyenne. Variety differences in the space planting experiment were non-significant.

Acre yield was greater with closer spacing (three inches) and higher seeding rate (approximately 110 pounds per acre), emphasizing the importance of plant population per unit area. The greater mean variety yield in the seeding rate than in the space-planted experiment was another point in support of the importance of plant population per unit area.

Yield per plant was greater in the wider plant spacing and lower seeding rates due to less inter-plant competition. This increase in yield was relatively small compared with the increase in plant number due to reduced spacing or higher seeding rate. Consequently, yield per unit area was increased with closer spacing and higher seeding rate.

For grain yield, the variety x seeding rate interaction was found to be significant at ten per cent level of significance, indicating a tendency for differential response of varieties.

Number of heads per square foot increased with an increase in seeding rates and decreased plant spacing. Tillering did not fully compensate for lower seeding rates.

Number of seeds per head decreased in the higher seeding rates and closer plant spacing due to greater inter-plant competition.

In the seeding rate experiment, variety ranking for number of seeds per head was found to be the reverse of that of the number of heads per square foot. This shows that varieties producing higher number of heads per unit area will produce fewer seeds per head.

Seed weight was found to be increased with the closer spacing and higher seeding rate.

Significant positive correlations ($r = .8594$ and $.5590$ in plant spacing and seeding rate experiment, respectively) were found between yield and number of heads per unit area in both the experiments. A significant correlation was also found between yield and seed weight in the seeding rate experiment. Number of heads per square foot was negatively correlated with the number of seeds per head and seed weight, and number of seeds with the seed weight.

The protein percentage of the grain increased with increased spacing and decreased seeding rate, probably because of more available nitrogen per plant.